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Small Rotenone Stations: A Tool for Studying Coral Reef Fish Communities

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ABSTRACT

Fish populations of 10 shallow-water stations were sampled repeatedly using small quantities of emulsified rotenone. Taking small samples is not unduly destructive and a complete kill is never obtained. Sampling errors appear to be random. Analysis of the collections indicates that approximately 75 percent of the species present are taken in a single sampling. Repopulation begins immediately and the effects of the sampling disappear four to nine months later. Repeated samplings can be used for Leslie-Davis population estimates. Resemblance indexes for samples from the same and different stations show that each area has a specific array of resident species. Transient species are less consistent in their occurrence. Sampling errors make it difficult to distinguish between transient and low-density resident species.

INTRODUCTION

Isolated coral patch reefs (fig. 1) are scattered throughout the Bahamas. These complex structures provide diverse types of shelter and consequently support large faunas of small fishes. It is not unusual to find as many as 70 or 80 species of fishes living together in a coral patch no more than 3 meters in diameter. The structure and development of these reefs have been discussed in detail by Storr (1964) and Milliman (1967).

Because they form discrete units that are spatially isolated from other reef areas, patch reefs are ideal for the study of coral reef fish communities.

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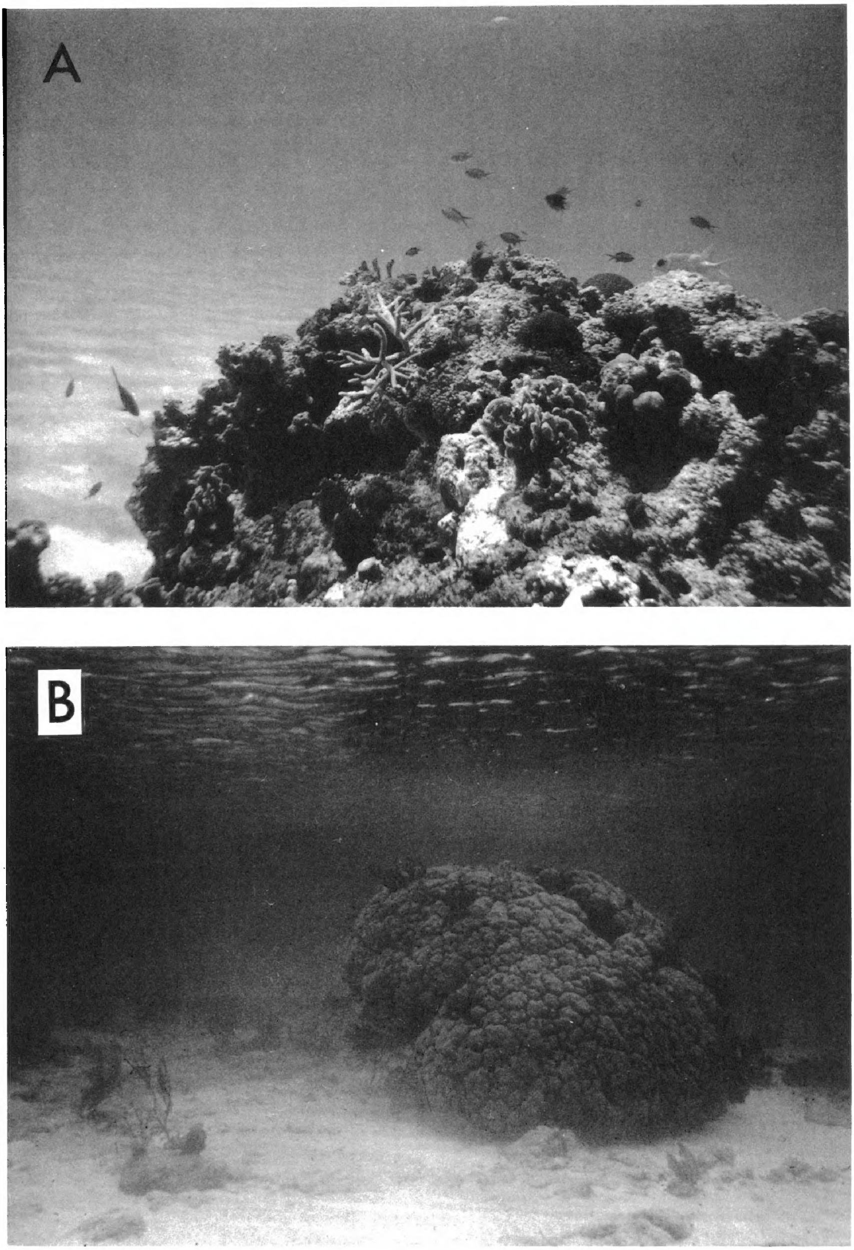

FIG. 1. A. Station I. Sixty-three species of fishes were collected in six samples from this isolated patch reef. The entire reef is approximately 4 by 5 by 3 meters. About one-half of the reef is visible in this photograph. B. Station VI. This patch reef is essentially a single *Montastrea* colony. Seventy-four species were taken in three collections.

It is especially fortunate that active systematic studies of the Western Atlantic fish fauna have provided us with the means of making reliable identifications of most of the species involved, and practical diving gear now permits direct sampling and observations of the species *in situ.*

The inadequacies of census and collecting techniques, however, are amplified in coral reef habitats where the labyrinthine nature of the substratum precludes the use of conventional nets and where traps are so selective as to be of value only for qualitative sampling. Although the clear waters of this region facilitate visual observation and counting, so many of the resident species are secretive, hole-dwelling, or nocturnal forms that these observations are of limited value for quantitative studies. The comparatively recent development of practical ichthyocides (toxic or soporific chemicals) has made it possible to sample these environments with a degree of thoroughness that is not attainable by any other method. The voluminous literature dealing with the use of chemicals for qualitative fish sampling or for control and eradication of populations of undesirable species need not be reviewed here.

Acknowledgments

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Methods

To obtain quantitative samples that can be used for comparisons of the fish assemblages associated with particular types of bottom structure, it is desirable to use small quantities of the ichthyocide, thus avoiding overkill and unintentional sampling of adjacent communities. It is also necessary to make a concerted effort to recover all the fishes that are affected by the chemical, and, as most of the fishes never reach the surface, it is necessary to use diving techniques to recover the stunned fishes. Self Contained Underwater Breathing Apparatus (SCUBA), even in water as shallow as 5 or 6 feet, permits the diver to reach under ledges and into crevices not otherwise accessible. The nets used must be of fine mesh to prevent the escape of the small specimens and strong enough to withstand abrasion

by coral and rough rock. DuPont nylon pattern 1400 (available from Marion Textiles, New York) has given excellent service. Frames approximately 7 by 12 inches with 6 inch handles, constructed of 3/8 inch brass rods are quite satisfactory. The net bag should be deep enough to fold over so that in deeper water the diver can confine specimens in one net while filling another, thus reducing the number of trips to the surface.

For safety and efficiency it is desirable to have a man remain at the surface in a boat to keep watch and assist the diver. In deep water a second diver is necessary. Several nets should be available so that when a diver surfaces he can exchange the full net for an empty one. While the diver is collecting more fishes the boatman carefully empties the net, preserving the fishes and discarding excess sand and debris. Occasionally the boatman is able to net afflicted fishes that come to the surface.

For quantitative sampling we have found that approximately 22 fluid ounces of emulsified rotenone (Chemfish Collector or Pronoxfish) applied from a plastic squeeze bottle (household detergent containers are ideal) produce excellent results. Before applying the rotenone the diver checks the currents by releasing a small amount of the mixture and watching the movement of the resulting cloud. Even with this precaution an unexpected tide change or eddy current can sometimes carry the rotenone away from the sample area. Such occurrences are noted, so that the sample results can be used with caution or eliminated from quantitative studies. We have obtained best results by applying the entire allotment of the chemical to a small area, perhaps 10 feet by 6 feet, so that a relatively dense cloud drifts across the sample area. Twenty-two ounces of rotenone effectively samples a patch reef 20 feet in diameter or a 100-foot section of shoreline before it becomes diluted beyond its effective concentration. When it is first released the rotenone forms a visible cloud but this soon disappears even though its concentration is still above lethal levels. As the rate of dispersion of the emulsion is dependent upon current velocity the best results are obtained in quiet water, and if the current velocity exceeds 3 or 4 feet per minute the sample may not be quantitatively reliable.

In general it is necessary to spend at least one-half to two hours picking up the fishes at each station. Cardinal fishes and some others will be affected almost immediately but certain eels react more slowly and continue to appear an hour or more after exposure to the chemical. The diver should continually check for stunned fishes outside of the affected area because individuals sometimes swim or drift a considerable distance before succumbing and settling to the bottom.

To draw meaningful inferences about the structure of communities we must have some assurances that the sampling data are to be trusted.

Assemblages of fishes are especially difficult to sample because the individuals are capable of swimming away to avoid capture or seeking refuge in deep holes, and it is unlikely that we will ever obtain complete samples without using methods that destroy the habitats. This is undesirable because it precludes any possibility of studying seasonal or successional aspects of the population dynamics.

It is difficult to evaluate the efficiency of rotenone stations because there is no other sampling method against which to check the results. We can, however, resample certain areas and compare the samples to see if our results are reproducible. In doing so we are measuring not the sampling error alone, but the combined effects of sampling error, naturally occurring changes in the population, and changes occasioned by the first sampling. Thus, the sampling error cannot be greater than the observed differences but it could be considerably less. Errors from all three sources are one-sided, that is, the actual number of species present can never be less than the number appearing in the sample and any errors must necessarily be underestimates.

STATIONS SAMPLED

The following stations in the Bahamas were resampled after elapsed periods of one day to 34 months:

Station I—Patch reef A, off west side of West Plana Cay. 4 m. by 5 m. by 2 1/2 m. high. Depth, 5 m. Latitude 22° 35.8′ N, longitude 73° 37.8′ W.
Sampled: March 20–24, 1966 and January 25, 1968.

Station II—Patch reef B, 3 m. by 4 m. by 2 m. high; about 10 m. east of Patch reef A, west side of West Plana Cay. Depth, 6 m. Latitude 22° 35.8′ N, longitude 73° 37.8′ W.
Sampled: March 21 and 23, 1966 and January 25, 1968.

Station III—Patch reef C, 4 m. by 4 1/2 m. by 2 1/2 m., 50 yards west of Patch reef A, depth, 6 m. Latitude 22° 35.8′ N, longitude 73° 37.9′ W.
Sampled: March 21 and 24, 1966 and January 25, 1968.

Station IV—Patch reef 3 m. by 4 m. by 3 m., off west side of Nurse Cay, Ragged Islands, depth, 4 m. Latitude 22° 28.6′ N, longitude 75° 50.7′ W.
Sampled: March 21, 1965; July 8, 1965 and January 12, 1968.

Station V—Section of patch reef, approximately 8 by 25 m. by 5 m. high, in Port Nelson Harbour, Rum Cay. Depth, 5 m. Latitude 23° 38.5′ N, longitude 74° 50′ W.
Sampled: June 18, 1964; April 6, 1965, and January 29, 1968.

Station VI—Coral head approximately 3 m. in diameter and 2 1/2 m. high near Salinas Point, Acklins Island. Depth, 3 m. Latitude 22° 13.3′ N, longitude 74° 17.5′ W.

Sampled: April 3, 1965; March 9, 1966, and January 16, 1968.

Station VII—Coral stack, 1 3/4 m. by 2 m. by 3 m. high, in West Bay, Little San Salvador. Depth, 5 m. Latitude 24° 35.5′ N, longitude 75° 56.8′ W.

Sampled: November 24, 1964; March, 1966 and February 1, 1968.

Station VIII—40 meter stretch of rocky shoreline near Southeast Point of Frazer's Hog Cay. Depth, 0 to 2 m. Latitude 25° 23.8′ N, longitude 77° 50.0′ W.

Sampled: (S64–30, S66–114, S68–72), July 14, 1964; December 13, 1966; February 4, 1968.

Station IX—West end of patch reef approximately 8 by 10 m. by 4 m. high. 1/2 mile north of southwest point of Little Inagua. Depth, 4 m. Latitude 21° 26.0′ N, longitude 73° 03.0′ W.

Sampled: March 18, 1966 and January 21, 1968.

Station X—Coral stack 3 m. high, off west side of Green Cay, Tongue of the Ocean, part of a larger patch reef approximately 8 m. by 10 m. Depth, 13 m. Latitude 24° 02.2′ N, longitude 77° 10.5′ W.

Sampled: (0830–0915, 1145–1230, and 1500–1545), January 10, 1968.

All specimens were identified and counted and these data were punched on paper tape. Programs written in the BASIC language for a time-share computer were used to compare the collections and summarize the data.

IMMEDIATE EFFECTS OF SAMPLING

Four of these stations were sampled within a short time period. Station I was sampled each day for five consecutive days. Stations II and III were resampled after two and three days, respectively, and Station X was sampled three times on one day. These samples can be considered as points in time as it is unlikely that there would have been much emigration or immigration in the few days between samplings.

Stations I, II, and III were separated from one another by open areas of white sand. Stations I and II were approximately 10 m. apart, Station III was approximately 50 m. from stations I and II. Some of the larger fishes such as *Epinephelus fulvus* (Linnaeus) and *Scarus* sp. were observed to swim from one to the other, but the smaller reef-dwelling species probably did not cross this area frequently.

The results of the five day series at Station I are presented in table 1. On the fifth day only one new species was added. Two of the species added by the fourth and fifth collections were sand-dwelling flatfish that cannot be considered reef residents. Very few individuals were present and thus the cumulative species curve had approached an asymptote, and it is unlikely that many resident species remained to be collected, although

TABLE 1
RESULTS OF SAMPLING STATION I ON FIVE CONSECUTIVE DAYS

	Sample Number				
	1	2	3	4	5
Number of species	34	25	22	18	5
New species	34	5	5	2	1
Cumulative total (species)	34	39	44	46	47
Number of individuals	208	51	57	52	6
Shannon-Wiener Index	3.848	4.341	4.026	3.594	2.252

more individuals were observed and the population of the reef was certainly not depleted.

It is, in fact, unlikely that a total kill is ever obtained. Certain species, for example *Chromis cyaneus* (Poey), *Chromis multilineatus* (Guichenot), and *Holocentrus ascensionis* (Osbeck), were sometimes observed to move up into midwater while the cloud was in the area only to settle back into their normal attitudes after the rotenone had drifted away. At most stations small fishes were seen moving into the area before the diver had finished picking up stunned fishes.

Used with proper precaution rotenone collecting is not more destructive than other collecting methods, such as spearing or trapping, and all the species are sampled instead of only those entering the traps or those that present an adequate target.

The Shannon-Wiener index ($H' = -\sum p_i \log P_i$) provides a method of describing the relative abundance of the component species. A large H' value results when a large number of species are represented by almost equal numbers of individuals; a low index indicates fewer species some of which are represented by large numbers of individuals. In the five-day series the Shannon-Wiener index at first increased, then decreased, as fewer species were taken. This suggests that in the initial samplings there was some selective cropping of the most abundant species, thus the remaining species were present in more nearly equal numbers.

Results of sampling two and three days apart (stations II and III) were more erratic, but they also showed changes in diversity index that can be ascribed to selective sampling (3.297 to 4.293 and 4.310 to 3.596 respectively).

The Shannon-Wiener index is probably an appropriate measure of

the species diversity for these samples because the samples are essentially unaffected by the lack of random distribution of the species within the sample area. For all practical purposes sampling is uniform as long as the rotenone reaches lethal concentrations throughout, and it makes no difference whether the individuals are randomly dispersed or concentrated in small clusters.

EFFECTIVENESS OF SINGLE SAMPLES

Stations I and X were sampled five and three times, respectively, in a short time period. At these two stations the first and second samples together contained 82.9 percent and 92.5 percent of the total number of species collected during the entire series. The first three samples at Station I contained 93.6 percent of the total. If we assume that these are representative, it appears that the first two collections contain approximately 85 percent and the first three contain at least 90 percent of the species actually present at the time of sampling. With these figures the total number of species at each of the four stations can be estimated, and from this it is possible to compute the efficiency of single rotenone stations.

These calculations for the four short-term stations are shown in table 2. Sample A of Station II was obviously unreliable. In comparison with stations I and III, from similar habitats, relatively few species were taken, and, furthermore, there was a disproportionately large number of species added by the second sample from Station II. At the other three stations the first sample contained 85.7–91.7 percent of the cumulative total after two samplings; at Station II the first sample contained only 52.6 percent, but the second contained 76.3 percent. An experienced collector would

TABLE 2

EFFECTIVENESS OF SINGLE SAMPLES[a]

Station No.	Species First Sample	Species First 2 Samples	Estimated Total Species Present	Percent First Sample
I	34	39	45.8	74.2
II	20	38	44.7	44.7
III	33	36	42.3	78.0
X	42	49	57.6	72.9
			Average	67.5
			Without Station II	75.03

[a] Four stations were sampled within three days. The number of species actually present is estimated on the assumption that the first two samples contained 85% of the species present.

have realized that the sample from Station II was unsatisfactory and would have excluded it from quantitative studies unless, as in the present case, it had been supplemented by other collections.

Even including the unreliable sample from Station II the average for the four stations was 67.5 percent of the estimated total number of species present. Without Station II, the average was 75.0 percent. It appears that it is reasonable to use 75 percent as a conservative estimate of the efficiency of single rotenone samples. Another way of looking at it is that the faunal list obtained from a single sample would have been increased by one-third if all the species present had been collected.

Station X provides an opportunity to test this estimate. Sampled three times in one day this patch reef yielded 53 species. If from analogy with Station I we assume that the three samples contained approximately 95 percent of the species present, the total fauna can be estimated at 56 (55.8) species. The first of the samples contained 42 species and increasing this by one-third gives a confirming estimate of 56 species in the population. If we assume that the first two samples contained 90 percent of the total we would have estimated the population at 59 (58.9) species.

When repeated samples at the same station are separated by periods of several months, the percent of the total fauna collected in any one sample is somewhat less because seasonal, successional, and random changes in the population are added to the sampling error. The results of resampling after longer periods of time (in most cases long enough for complete recovery of the population) are summarized in table 3. For this table it was assumed that the three stations contained 90 percent of the species actually present when the samples were taken. The average yield of a single sample was 55.6 percent and the average of two samples was 76.4 percent. These figures are perhaps less significant as indicators of sampling error than as indicators of the stability of the communities. In view of the mobility of tropical marine shore fishes, it is not surprising that some different species will be encountered at different times.

The resemblance between two samples can be quantified by the use of any of several indexes. Simpson (1946) has reviewed some of these as used for quantifying the similarity between faunas from different geologic ages and different geographic regions. Peters (1968) has elaborated on this discussion and provided computer programs for the computation of some of these indexes. Such indexes can be used for comparing successive samples from the same locality.

Three different indexes are used here. The first: $A = {}^{C}/N$ is based on the number of species occurring in both samples (C) as a proportion of the total number of species in the two samples (N).

TABLE 3

EFFECTIVENESS OF SAMPLES TAKEN SEVERAL MONTHS APART[a]

Station No.	No. of Species in 3 Samples	Estimated Total Species	Samples 1 No.	Samples 1 Percent	Samples 2 No.	Samples 2 Percent	Samples 3 No.	Samples 3 Percent	Samples 1 and 2 No.	Samples 1 and 2 Percent	Samples 2 and 3 No.	Samples 2 and 3 Percent	Samples 1 and 3 No.	Samples 1 and 3 Percent
I	56	62.2	34	54.7	25	40.2	42	67.5	39	62.7	50	80.4	53	85.2
II	49	54.4	20	36.7	29	53.3	31	56.9	38	69.9	43	79.0	39	71.7
III	40	44.4	33	74.3	18	40.5	24	54.1	36	81.1	32	72.7	38	85.6
IV	82	91.1	43	47.2	58	63.6	54	59.2	69	75.7	78	85.6	63	69.2
V	52	57.8	20	34.6	33	51.1	31	53.7	39	67.5	47	81.3	41	70.9
VI	74	82.2	46	56.0	39	47.4	51	62.0	57	69.3	61	74.2	68	82.7
VII	72	80.0	55	68.7	37	46.3	40	50.0	64	80.0	54	67.5	65	81.3
VIII	91	101.1	53	52.4	62	61.3	67	66.3	75	74.2	81	80.1	82	81.1
IX	58[b]	68.2	48	70.4	37	54.2	—	—	58	85.0	—	—	—	—
X	53	58.9	42	71.3	31	—	18	—	49	83.2	37	62.8	47	79.8
Average				56.63		51.54		58.71		74.86		75.96		78.61

[a] All stations except Station IX were sampled three times. It is assumed that the three samples contain 90% of the species present and from this the percentages of the total fauna taken in single samples and in pairs of samples have been computed.

[b] Two samples 85% basis.

Simpson recommended the use of a similar index: $B = {}^{C}/N_1$ which is the number of species common to both collections as a proportion of the number of species in the smallest sample. This is a conservative index that is appropriate when the sampling effort is unknown but it nullifies the effect of different catch sizes and obscures differences that are important in evaluating sampling effectiveness. For example, at Station X, sampled three times in one day, there was a progressive decrease in the number of species collected. The first index reflects this but the second indicates a greater similarity between the first and third collections than between the first and second because the third collection contained a higher proportion of species that were also in the first than did the second collection.

The third index takes into account the relative abundance of the species in both samples.

$$C = \left(\frac{Ic1}{I1} + \frac{Ic2}{I2}\right) \times .5$$

Where: Ic1 is the number of individuals belonging to species that are in the first sample that are present in both samples.

Ic2 is the number of individuals in the second sample that belong to species that are present in both samples.

I1 is the total number of individuals in the first sample.

I2 is the total number of individuals in the second sample.

These three resemblance indexes for the samples taken at the 10 stations are tabulated in table 4.

The inadequacies of the first sample from Station II (referred to above) are reflected in its low resemblance to the first sample as measured by index A, but this is obscured by indexes B and C; B because of its small total species list and C because the individuals taken tended to belong to the commonest species that are most readily collected so that they are represented even in unsatisfactory samples.

At all the short term stations (I, II, III, and X) the second sample was taken less than three days after the first, hence was biased by the first. The third sample, taken long enough afterward for the population to have returned to equilibrium, is independent. For stations I and III, the index C, based on individuals, indicates a closer resemblance between the first and third samples than between either the second and third or the first and second. The other two indexes show no clear trend to reinforce this. This suggests that the proportion of resident individuals in the population remains fairly constant. I have been unable to detect any correlation between time of the year when the collections were made and the three indexes. Correlation coefficients between lapsed time and resemblance

TABLE 4

COMPARISON OF THREE RESEMBLANCE INDEXES

Station No.	$A = C/N$			$B = C/N_1$			$C = \left(\frac{Ic1}{I1} = \frac{Ic2}{I2}\right) \times .5$		
	Samples								
	1 and 2	2 and 3	1 and 3	1 and 2	2 and 3	1 and 3	1 and 2	2 and 3	1 and 3
I	.513	.340	.434	.800	.680	.676	.780	.699	.894
II	.289	.395	.308	.550	.586	.600	.727	.760	.708
III	.417	.312	.500	.833	.556	.792	.753	.676	.887
IV	.464	.436	.540	.744	.630	.791	.888	.939	.925
V	.359	.362	.244	.700	.548	.500	.840	.794	.681
VI	.491	.475	.426	.718	.744	.630	.867	.847	.848
VII	.438	.426	.462	.757	.622	.750	.904	.871	.882
VIII	.533	.593	.463	.755	.774	.717	.862	.942	.885
IX	.466	—	—	.730	—	—	.697	—	—
X	.490	.324	.277	.774	.767	.722	.922	.746	.846

indexes A, B, and C were .083, —.387, and .099, respectively. None of these indicate any strong trend with passing time.

It appears, therefore, that seasonal and successional changes if they occur at all are not especially marked. There is evidence that larger suprabenthic species wander a great deal, remaining varying lengths of time whenever they find a suitable habitat (Smith and Tyler MS). Our greatest sampling error is undoubtedly from these free-moving species and their presence or absence is undoubtedly more variable. This would account for the greater stability of the indexes based on relative number of individuals as opposed to indexes that consider only the taxa present. A single individual of a wandering species would add a new species to one of the samples but its effect on the total number of individuals would be small.

DURATION OF THE EFFECTS OF SAMPLING

Although the series of tests described above indicate that the population is not completely eliminated by sampling with rotenone, there can be no doubt that the sampling affects the population and disturbs the balance within the community structure. Analysis of the species collected in the test samples suggests that the effects of sampling are apparent in the sample taken four months after the initial sampling but not in samples taken nine months or more after the first sampling. This has not yet been thoroughly studied and experiments are now being planned that will lead to a better understanding of the duration of such effects.

Resampled after four months, Station IV included at least four species that are not usually collected in patch reefs in shallow waters on the bank sides of islands. These are *Apogon lachneri* Böhlke, *Inermia vittata* Poey, *Malacoctenus boehlkei* Springer, *Lythrypnus spilus* Böhlke and Robins and possibly a species of *Starksia*. All of these species, however, are frequently collected at deeper localities and usually on the outer shelf of the bank. A reasonable explanation for their presence in the four-month sample would be that niches acceptable to them had been opened by removal of the previous residents through the initial sampling. Intraspecific geographic variation within the Bahamas is either minimal or absent for the few species we have investigated, suggesting that planktonic larvae are dispersed throughout the archipelago. Apparently some of these larvae were able to establish themselves in the vacated niches, only to be replaced eventually by the better adapted species that normally constitute the community in this kind of environment.

Dammann (1969) reported a series of experiments in which a reef in the Virgin Islands, 75 by 120 by 30 feet, was rotenoned in June and

September, 1968. The reef was isolated by surrounding it with fine netting except for a three-week period after the first poisoning. The second collection contained slightly more individuals and greater biomass than the first but there were some different species. Five families were represented only in the second collection and six families only in the first collection. Both Dammann's report and my own observations indicate that repopulation occurs in a few weeks but it takes on the order of four to nine months for the population to return to an equilibrium state.

At all of our stations the samples were taken more than nine months apart and there were no species that could be recognized as belonging to communities of other habitats.

POPULATION ESTIMATES FROM REPEATED SAMPLINGS

Repeated samplings, each of which has a significant effect on the total population of an isolated area, can be used for population estimates according to the methods of Leslie and Davis (1930). This method consists of plotting the number of individuals taken in successive samples against the previous cumulative total number of individuals collected. A straight line is then fitted by eye and the intercept with the abscissa will be an approximation of the original number present (refinements in the method of fitting the line proposed subsequently are probably not justified for the small numbers in our samples). Three samples are needed but there is little increase in accuracy if additional samples are used although all five samples from Station I were used for the calculations.

Satisfactory results can be obtained only for the most abundant species, particularly those that appeared in all three samples, and for the total populations. The results obtained for stations I and X are given in tables 5 and 6. A comparison of estimated population with numbers collected indicates that the three samples at Station X and five samples from Station I resulted in the collection of somewhat more than 90 percent of the population. This seems to agree with subjective impression from field observations.

As these reefs are not completely isolated, and there may have been some interchange of individuals between stations I and II, we cannot place absolute reliance on this method. Nevertheless, Leslie-Davis population estimates offer promise for future studies of this kind of habitat.

Size of the Sample Areas

Isolated patch reefs are ideal for study of communities but other habitats can also be sampled by means of small rotenone stations. Station VIII is a stretch of rocky shore line and there is nothing about the results of a

TABLE 5

LESLIE-DAVIS POPULATION ESTIMATES FOR STATION I[a]

	A	B	C	D + E	Total Estimated	Total Collected	Percent of Total Collected
Kaupichthys hyoproroides (Strömman)	5	4	3	1	16	13	81.3
Scorpaenodes caribbaeus Meek and Hildebrand	6	1	—	1	8	8	100.0
Pseudogramma bermudensis (Kanazawa)	7	1	2	—	9	8	88.9
Chromis multilineatus (Guichenot)	4	3	—	3	18	10	55.6
Thalassoma bifasciatum (Bloch)	18	4	6	14	43	42	97.7
Labrisomus gobio (Valenciennes)	4	2	—	2	9	8	88.9
Malacoctenus triangulatus Springer	5	2	3	1	13	11	84.6
Starksia atlantica Longley	32	5	—	1	40	38	95.0
Starksia lepicoelia Böhlke and Springer	39	6	10	6	62	61	98.4
Enneanectes altivelis Rosenblatt	40	14	2	4	62	60	96.8
Other species					150	128	85.3
Grand Total					430	387	90.0

[a] Columns 1–4 are the numbers collected in the samples, column 5 is the number estimated to be present, using graphic methods, and column 6 is the total number actually collected. The last column gives the percent of the estimated population that was taken in the three samples.

TABLE 6

LESLIE-DAVIS POPULATION ESTMATES FOR STATION X[a]

	A	B	C	Total Estimated	Total Collected	Percent of Total Collected
Gramma loreto Poey	8	5	4	22	17	77.2
Thalassoma bifasciatum (Bloch)	15	9	2	30	26	86.7
Halichoeres garnoti (Valenciennes)	9	1	2	13	12	92.3
Scarus croicensis Bloch	3	1	2	7	6	85.7
Coryphopterus personatus (Jordan and Thompson)	358	64	39	475	461	97.1
Coryphopterus glaucofraenum Gill	15	4	5	24	24	100.0
Coryphopterus eidolon Böhlke and Robins	10	10	7	60	47	45.0
Gnatholepis thompsoni Jordan	5	10	4	20	19	95.0
Lythrypnus spilus Böhlke and Robins	4	3	1	9	8	88.9
Other species	81	55	21	160	157	98.1
Grand total	508	162	87	820	757	92.3

[a] Columns 1–3 are the numbers collected in the samples, column 4 is the number estimated to be present, using graphic methods, and column 5 is the total number actually collected. The last column gives the percent of the estimated population that was taken in the three samples.

series of samplings to suggest that the results are any more or less reliable than the results obtained from patch reefs. Some of the species that seem to be stragglers are perhaps the result of sample "contamination," the unintentional sampling of contiguous environments. Future studies on the behavior of the member species, particularly studies of territory size will be useful as criteria of size of area to be sampled.

Low-density species may also be useful as an indication of the effectiveness of a particular sample. For example, a low density species of deeper reefs along the edge of the Bahamian Banks is *Lucayablennius zingaro* (Böhlke). This species does not occur in large numbers as does *Gramma melacara* Böhlke and Randall, which is also an indicator species for collections from comparable depths, but most collections contain one to three specimens. One might speculate that a rotenone station large enough to include the entire home range of at least one individual will sample this species. If the area affected by the chemical is smaller than a complete range, the blenny can retreat to a safe area within its home range and avoid capture.

If these speculations are borne out we may be able to add objective criteria to our subjective impressions of the effectiveness of a particular sample.

Random Sampling Error

It is instructive to examine the patterns of occurrence of species in the collections. Some species occur only in one of three samples, others in two, or in all three (table 7). A disproportionate number of species occur in more than a single collection, and it is instructive to compare their frequencies with the frequency that would be expected on chance alone.

Stations IV, V, VI, and VII are patch reefs that were sampled three times with adequate time between sampling to permit the population to return to equilibrium. In all, 141 species were taken in the twelve samples from these four stations. Sixty-three species occurred at only one station, 35 occurred at two, 28 at three, and 15 at all four stations. Furthermore, those species occurred in one, two, or all three samples from the stations at which they were present. For example, 28 species were present at three stations. Three were taken in all three samples from all three stations, nine were taken in all three samples from two of the three stations, 11 in all three samples from one of the three stations, and five were never collected in more than two samples from any of the three stations. If the presence of the species in any particular sample is purely a matter of chance we can calculate the expected number of species occurring in all three samples from the stations where it was present by a Poisson distri-

TABLE 7

CONSISTENCY OF OCCURRENCE OF CORAL REEF FISHES FROM TEN SAMPLING STATIONS

Station No.	1 Sample		2 Samples		3 Samples		At Least 2 Samples		Total No. of Species Collected
	Number	%	Number	%	Number	%	Number	%	
I	26	46.4	15	26.8	15	26.8	30	53.6	56
II	27	55.1	13	26.5	9	18.4	22	44.9	49
III	14	35.0	17	42.5	9	22.5	26	65.0	40
IV	36	43.9	19	23.2	27	32.9	46	56.1	82
V	29	55.8	14	26.9	9	17.3	23	44.2	52
VI	36	48.6	14	18.9	24	32.4	38	51.4	74
VII	33	45.8	18	25.0	21	29.2	39	54.2	72
VIII	35	38.5	21	23.1	35	38.5	56	61.5	91
IX	31	53.4	27	46.6	—	—	27	46.6	58
X	26	49.1	16	30.2	11	20.8	27	50.9	53
Average		46.7		27.2		26.3		53.1	

TABLE 8

COMPARISON OF OBSERVED AND EXPECTED NUMBER OF SPECIES OCCURRING IN ALL THREE SAMPLES FROM FOUR PATCH REEF STATIONS[a]

No. of Stations Where Species Were Present	No. of Stations Where Species Appeared in All Three Samples: 0	1	2	3	4	Total
1	60	3	—	—	—	63
	(60.05)	(2.86)	—	—	—	
2	23	11	1	—	—	35
	(24.15)	(8.97)	(0.17)	—	—	
3	5	11	9	3	—	28
	(7.20)	(9.80)	(6.60)	(3.00)	—	
4	4	3	5	1	2	15
	(3.00)	(4.80)	(3.90)	(2.10)	(0.80)	

[a] Expected frequencies, in parentheses, are calculated as Poisson distributions.

bution. The expected frequencies (in parentheses) are compared with the actual frequencies in table 8. Although the samples are rather small to be completely reliable, chi-square tests indicate no significant deviation from the frequency distribution calculated on the basis of random occurrence. In a habitat that is acceptable to it, the presence or absence of a given species in a particular sample is a matter of chance. The most likely explanation seems to be that the species are almost always present but sometimes are missed by sampling errors that are essentially random. At least no great bias is introduced by the sampling technique.

MICROHABITAT SPECIFICITY

Of the 141 species collected at stations IV, V, VI, and VII, 39 (27.6%) occurred in all three samples from their respective stations. On the basis of random errors we would expect that at least as many, and, more likely, twice as many, others were present at the stations during all three samples. This indicates that more than half of resident species are constantly present, in other words, acceptable microhabitats are consistently occupied by fish species that are adapted for them.

At present we know little about the specific niches of coral reef fishes[1] and it is probably fair to say that we do not have a precise characterization of the niches of a single species of reef fish with the possible exception of a

[1] I use niches in the plural because most fishes modify their mode of living during different phases of their life cycle and under different competitive climates.

few aberrant associations such as the pearlfish, the anemone fishes, and some of the sponge-dwelling gobies. Certainly we are not now able to define adequately the features that adapt a species for a particular way of life.

The fauna present at a particular time consists of residents that actually belong to the community, and stragglers, those members of wide-ranging or mobile species that occasionally pass through the area without becoming a resident member of the community. Stragglers can be recognized by two criteria. First, they appear sporadically, in this case in single samples. Second, they appear as consistent members of some other community. Needlefishes, for example, are surface-dwelling forms that sometimes are collected accidentally at coral reef stations. Certainly, their contribution to the ecology of the reef is minimal and by no stretch of imagination can they be considered part of the infaunal community of that reef. On behavioral grounds, Gooding and Magnuson (1967) recognized two kinds of nonresident species, viz., transients that pass through the area without reacting to the substrate and visitors that react but only remain around the area a short time—"several minutes to an hour." Unfortunately, this important distinction cannot be made from our material.

Classification of any particular species as a straggler, however, must be done with caution because there are some low-density forms having large home ranges that may be represented by only one or two individuals per station. These stand a good chance of being missed by the collecting methods and records would therefore show a pattern of occurrence similar to that of the stragglers, whereas they are in fact members of this community and no other.

Species may be stenokous, adapted for a few specific niches, or they may be euryokous, adapted for a variety of niches. Furthermore, they can be well adapted, in which case they will be able to occupy their niches regardless of the climate of interspecific competition that is present, or opportunistic species, occupying particular niches only in the absence of better adapted species. Presumably most or all species are well adapted for their optimal niche and opportunistically adapted for other niches. This can be represented by a graph of degree of adaptation. A bell-shaped curve indicates high adaptation for the preferred niche and low adaptation for adjacent niches. Euryokous species would occur in a variety of microhabitats; stenokous forms would be restricted to the specific niches for which they are well suited. It is unlikely that any species can be both well adapted and euryokous as stenoky can only be achieved at the expense of versatility.

The distinction between these two strategies is of fundamental impor-

tance to our understanding of community homeostasis because stenokous forms will occupy their niches regardless of the presence of other species, whereas the more versatile euryokous species will be easily displaced by competitors. Stenokous species therefore exert a high degree of control on the community structure.

Judgment as to whether a species is stenokous or euryokous must be made with caution, however, for ubiquitous species may actually be steno-adapted to generalized niches that occur in a wide variety of habitats.

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